EXPLORING DESIS FOR INLAND WATER QUALITY IN SPANISH RESERVOIRS

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ABSTRACT:

In a first approximation to the use of hyperspectral DESIS data to ocean colour applications in inland waters, we present here a comparison of the DESIS vs. MSI spectra from two reservoirs located in the province of Valencia. Benagerber and Tous are two small, oligo-mesotrophic reservoirs in need of constant water quality monitoring. These preliminary results have shown us the advantages and limitations of DESIS imagery for these types of dark and small lakes, but also pointed out the need for a specific over water atmospheric correction, as well as further understanding of the band combinations that can lead to accurate water quality parameter estimations.

1. INTRODUCTION

The role of freshwater ecosystems in global biodiversity and ecology is undeniable. With a global coverage of only 0.8% of the Earth, more than 10% of all animal species and 35% of all vertebrate species live in these environments. (Stendera et al., 2012). Freshwater is particularly vulnerable to climate change, with land use, eutrophication and habitat destruction being the most relevant, and mainly anthropogenic, stressors. Monitoring the state of these ecosystems as sources of water for consumption, recreation, energy and food is a tremendous effort that can be achieved by using different methods. Observing changes in water quality though ocean colour techniques is one approach that helps to understand how different processes affect water quality: from the collection of samples *in situ*, the increased use of satellite remote sensing -not always suited to the purpose-, to the more popular use of sensors on drones and unmanned aerial vehicles (UAV), some even hand-held, the possibilities grow every day. Currently, the Copernicus Global Land Service (CGLS) covers Vegetation, Energy, Cryosphere, Hot Spots, and Water, providing public access to state-of-the-art products derived from EO sensors. In the Water category, it currently provides Lake Surface Water Temperature (LSWT), Lake Water Quality (LWQ), Water Bodies (extent) and Water Level. The CGLS Lake Water Quality product has been applied to a large number ($\sim$ 4264) of permanent and seasonal water bodies, natural lakes and artificial reservoirs, with an area larger than 50 ha (0.5 km^2). The selection of lakes was based on the size and shape of the water bodies suited to earth observation (EO) data retrieval. The EO data used for deriving water quality parameters are mainly the specifically designed ocean (water) colour sensors such as Sentinel-3 OLCI (ESA). Other ocean colour sensors, but ones less suited to inland waters due to their spatial and spectral resolution, are MODIS onboard AQUA (NASA), VIIRS onboard Suomi NPP and NOAA-20 (NOAA). Sentinel-2 Multi Spectral Image (MSI), with improved spatial resolution (up to 10 m) is being used in the service, via demonstration products, for covering smaller water bodies, with downsampling to spatial resolution of 100 m.

Lakes, reservoirs, estuaries, lagoons and marshes represent a mixture of optically shallow and deep waters, with a high gradient of optical water types: from clear to turbid, from oligotrophic to hypertrophic. The development and application of accurate atmospheric correction and bio- optical algorithms applied to optical remote sensing are big challenges over such variable aquatic ecosystems (Giardino et al., 2019). There are two types of data needed to perform satellite EO services of inland water quality. The first is optical data, such as water leaving reflectances, needed for validating atmospheric correction (the most critical step within EO water quality retrieval). The second type is the in-water parameters that characterize the quality of the water. The EU MONOCLE Project (https://monocle-h2020.eu/Home) reviewed the water quality data needs for a range of practitioners and stakeholders. The survey results highlighted that data on nutrients was selected as the most important WQ parameter needed, followed by other chemical (dissolved oxygen) and biological (chlorophyll-a) water quality parameters. Using multispectral EO sensors, it is possible to derive chlorophyll-a, turbidity and total suspended solids. A lake receives and recycles organic and inorganic substances from within the lake, from its watershed and beyond. This results in high optical variability. Hyperspectral remote sensing of inland water opens up exciting lines of research in these optically complex waters. These datasets have narrower spectral bands in positions that focus on key biophysical properties of the water column and benthic properties. High spectral resolution data provides more spectral bands, which are needed to untangle a greater number of variables in the water column (Hestir et al., 2015).

Our study area is located in the eastern part of the Iberian Peninsula. In this ongoing analysis, the hyperspectral signature of DESIS is compared to a reference spectral signature from MSI to qualitatively determine the fitness for purpose of the DESIS images. We also made a preliminary analysis on optical water types (OWT) clustering using unsupervised methods and a reduce set of DESIS bands.

2. DATA AND METHODS

2.1 Datasets

The number of hyperspectral sensors available for remote sensing studies is still limited, and some are mission-specific

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sensors aboard the International Space Station (ISS). The two main drawbacks of these sensors are the low temporal resolution and limited spatial coverage. From satellite, the first hyperspectral imager was EO-1 Hyperion, followed by others onboard the ISS like HICO and ECOSTRESS. European missions like PRISMA or DESIS are now in place. Future missions like EnMAP, HypXIM, SHALOM, PACE, SBG and GLIMR will expand the observations to global oceans and terrestrial ecosystems in different spectral, spatial and temporal resolutions. To perform our analysis we will use two DESIS images provided by DLR focused on our study area. We will complete the analysis with multispectral data from MSI and, in the near future, spectra from *in situ* measurements (publication in process).

The DLR Earth Sensing Imaging Spectrometer (DESIS) onboard the International Space Station (ISS) takes measurements in the spectral range from 400 to 1000 nm with a spectral sampling distance of 2.55 nm and Full Width Half Maximum (FMWH) of about 3.5 nm (Alonso et al., 2019). It has a spatial resolution of 30 m, making it an appropriate pixel size for studying medium to small inland waters.

The Sentinel-2 satellites are part of the Copernicus Programme (European Commission and European Space Agency), which have on-board the MultiSpectral Instrument (S2-MSI). Though S2-MSI was designed for land studies, it has optimized spatial and radiometric resolutions that makes it suitable for monitoring lakes and reservoirs with a reduced surface area. MSI images have been atmospherically corrected using the standard Sen2Cor and the Case 2 Regional Coast Colour (C2RCC) algorithms (Brockmann et al., 2016), which has proven to give back good results in this Mediterranean area (Pereira-Sandoval et al., 2019). C2RCC provides biophysical water quality parameters (chlorophyll-a, total suspended matter, absorption of colored dissolved organic matter) that have been validated in the reservoirs of interest by (Urrego et al., 2020).

2.2 Methodology

DESIS hyperspectral data is available at different processing levels containing radiances (Level 1) or surface reflectance (Level 2). To obtain water leaving radiance or remote sensing reflectance, an atmospheric correction should be applied to the Level 1 data. DESIS uses the ATCOR software (DESIS-PAV, 2015). This L2A processor is designed for AC over land, but there are regular improvements to adapt it to inland waters as well. We had the opportunity to observe these improvements since we analysed two different versions of the AC results on our lakes over the past months using the EOWEb portal (https://eoweb.dlr.de/egp/). The results presented here correspond only to the AC version 02.13. The images downloaded are from 21 February 2020.

As we have already pointed out, the first step possible is to compare the spectra with other sensors that have been shown to be useful in deriving WQ parameters with high level of accuracy, like the Sentinel-2 MSI. After this preliminary analysis, the next steps will be to analyse the data quantitatively and determine which bands are fitter for the water types in our study area. Since the number of bands is very high (235), dimensionality reduction techniques will be applied to keep the most important components for the study case. This reduction is usually done via principal component analysis (PCA) or other approaches, like the minimum noise fraction (MNF). This analysis is very useful because many bands can display similar reflectance properties and be highly correlated. Determining which bands are the most appropriate for WQ estimations is challenging and in many cases depends on the optical water types.

2.3 Study area

The reservoirs in this case study are the Benageber and Tous lakes, in the province of Valencia (Figure 1). Both are man-made reservoirs after dam construction in the Turia and Jucar rivers, respectively. Table 1 contains information about some physical characteristics of the reservoirs. Following the indicators measured on several field campaigns (Pereira-Sandoval et al., 2019), these reservoirs are classified as oligotrophic to mesotrophic (Chl-a $<$ 25 (mg/m^3) and $Z_{sd} > 3$ (m)).

Table 1. Main characteristics of the reservoirs.

	Tous	Benagber
Mean surface ares (km^2)	12.06	9.8
Distance to Sea (km)	78	39
Meters above m.s.l	530	163
Shoreline Development Ratio	4.1	4.

Figure 1. Reservoirs in the province of Valencia, Spain

The Benageber dam (1952) has made possible the extension of the irrigated area of the lower Turia. The dam generated the 208 Hm3 reservoir (Figure 2, top). The Tous dam is built at the end of the last mountainous section that crosses the Jucar (Figure 2, bottom), immediately before the landscape transforms into a wide plain that looks out over the Mediterranean. It has a large capacity reservoir (378 Hm3 at maximum normal reservoir and 792 Hm3 at maximum extraordinary level) and a large spillway (Confederación Hidrográfica del Jucar: https://www.chj.es/). Both reservoirs are located in the upper corner (Benagber) and bottom corner (Tous) of the DESIS images.

3. RESULTS

3.1 Spectra comparison

Spectra from the area where the *in situ* measurements are usually taken in the two reservoirs is used to compare the spectral profiles (irradiance reflectance) obtained from DESIS with the spectra from MSI images (2020-02-20) of one day before the DESIS images were taken. Both water masses present very low reflectance, with the highest values between 0.002 and 0.018. Infrared values (> 700nm) are negligible in both cases.

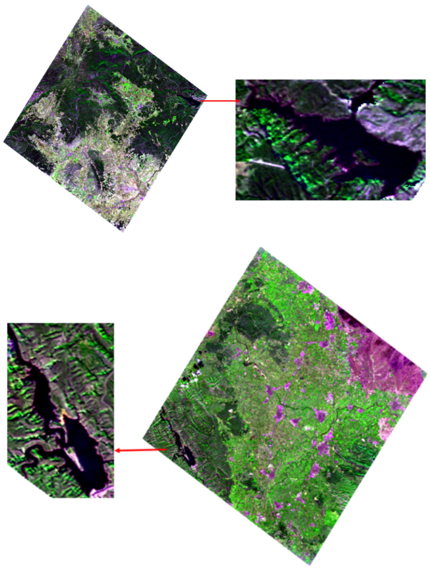

Figure 2. Benageber reservoir, (top) and Tous reservoir (bottom) Valencia, Spain

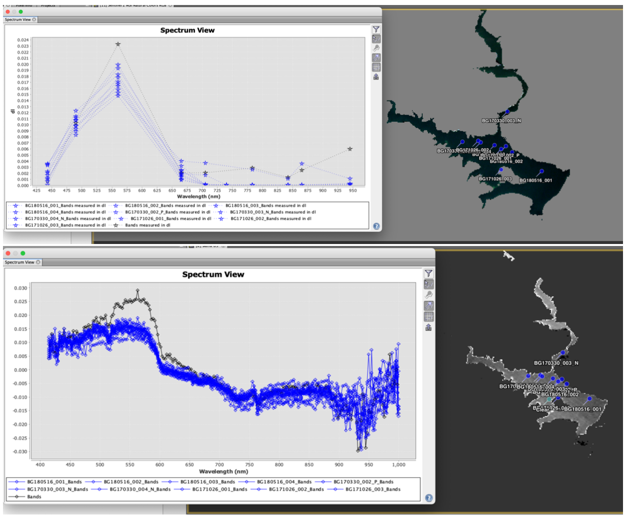

Figure 3. S2-MSI (top) ans DESIS (bottom) spectral signatures, Benageber reservoir

If we compare MSI signature with the spectral signature from the DESIS, we can observe a certain similarity in the shape and magnitude, with some relevant differences. In Benageber (Figure 3) we see a peak around the 550nm in MSI, which is also visible in the DESIS set. There is a strong drop in the signal from 600 nm in DESIS, with red and infrared bands showing negative values. In MSI the signal decays from 650 nm and on, but it still shows positive values in the red and NIR bands. In Tous (Figure 4), the blue part of the spectrum (400-450 nm) gave negative values in DESIS, so they were removed from the plot for a better understanding of the behaviour of the other spectra. Tous shows even lower values than Benageber (average maximum at 0.005 in the MSI temporal series of 2019, nor shown here) and we observe again the drop in slope from 600 nm in the DESIS data, in this case more similar to the behaviour of the MSI set (decay from 650 nm). This kind of behaviour is expected since the AC used in DESIS (ATCOR) and MSI (Sen2Cor) are designed for land monitoring, and dark targets like clear waters or water with a high CDOM content are perceived as black since they reflect less than 1% of the incident light. This issue raises concerns about the usability of DESIS imagery for these types of inland optical water types.

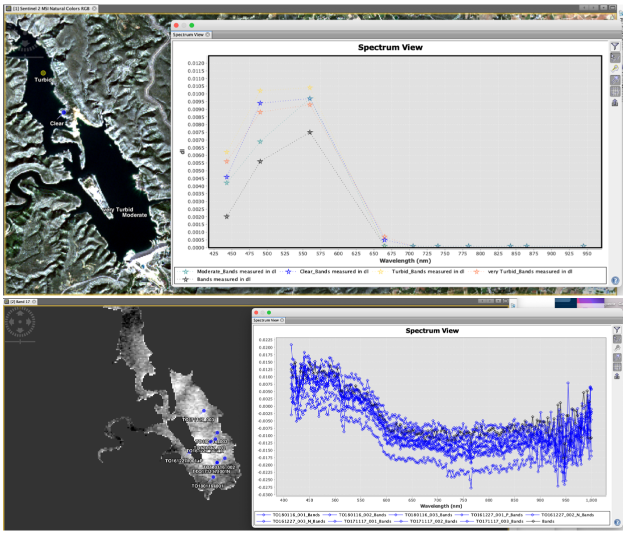

Figure 4. S2-MSI (top) ans DESIS (bottom) spectral signatures, Tous reservoir

3.2 Optical Water Types

Since we are preparing another study about machine learning for optical water types with MSI, we tested an unsupervised method of clustering with the K-means classifier. We applied the same approach to MSI and DESIS and compared the results. For making both comparable, we use the bands between 412 and 700 nm (Figure 5). Results look very promising, the four clusters separated by K-means within the DESIS bands are in good correspondence with the change in the magnitude of the spectral signature shown in Figure 4. In addition, it seems to improve the water limits detecting quite well a larger part of the river up north.

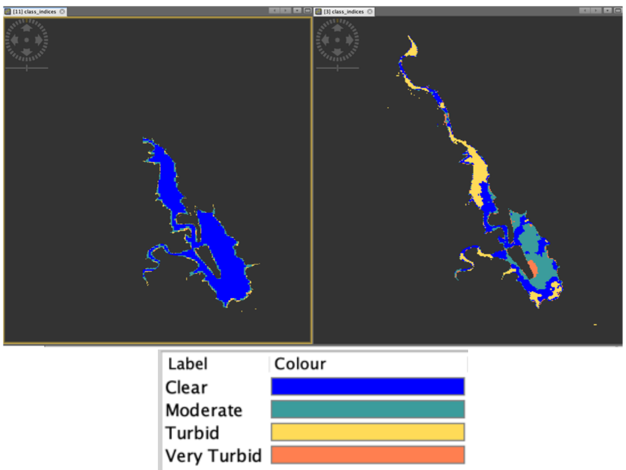

Figure 5. MSI vs. DESIS K-means clustering, Tous reservoir

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4. DISCUSSION

The standard atmospheric correction applied to the DESIS sensor, designed mainly for land monitoring, shows some constraints when it comes to detecting water spectra in inland waters. In the literature, positive results have been documented in some areas like Lake Constance, Lake Peipsi, Lake Maggiore, Lake Garda and some Finnish lakes (Pinnel et al., 2019). Hyperspectral data has proven useful for detecting phytoplankton blooms thanks to the one peak at 565 nm using the Fluorescent Line Height algorithm ((Dierssen et al., 2020)). (Bernardo et al., 2017) showed an improvement in the TSM detection using the bands from 700-850 nm available in OLI (Landsat-8), which can be found in DESIS as well, for more complex water types.

In any case, there are some considerations that should be taken into account when working with hyperspectral data as we can currently obtain it. For instance, the number of coincident images of the exactly same area can be low due to the difference in time acquisition and view angles; overpass predictions are not as certain as they are with orbiting satellite sensors, which can affect the necessary parallel field work; other issues can be caused by misregistration errors (Pahlevan et al., 2021).

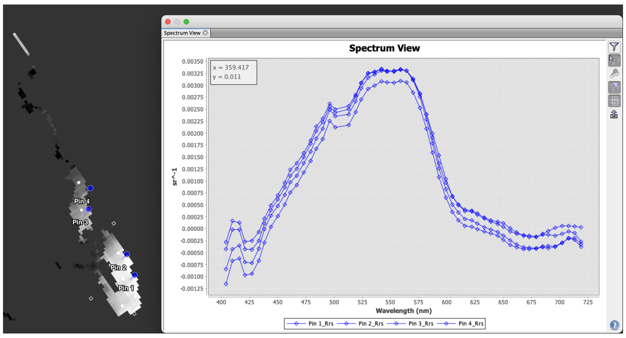

Figure 6. HICO Rrs reflectance, Tous reservoir

The preliminary observations made here show limitations of the sensor in our lakes. These constrains could be due to the type of waters; however, the location of the lakes at the edges of the images rises also questions about possible geometric or radiometric miscalibrations. In order to check how location could affect the estimated radiometry, we downloaded a HICO image that shows the Tous reservoir in a more centered position, and use l2gen (SeaDAS-OCSSW) to atmospherically correct it. Results of the R_{rs} spectrum in Figure 6 look quite different to the DESIS signal; consideration about the date of the image (2012-02-26) should be raised here, what makes difficult a proper comparisons.

Nonetheless, due to our interest in hyperspetral water quality applications, and knowing that DESIS AC and image processors are in constant evolution, we would like to continue with the research on the matter. Adding new reservoirs or natural lakes or lagoons (Albufera de València) or even coastal areas (Manga del Mar Menor) with more complex water types is the following step. We are currently developing a study about temporal OWT changes in different lakes in Valencia, compiling a dataset of labelled water-leaving reflectances and WQ parameters (Pereira-Sandoval et al., 2021). The results of this study that could be used to tune WASI to estimate WQ parameters. We are also working on chlorophyll-a estimations with WASI and its comparison with in situ data, but some more planning must be done for finding reasonable match-ups.

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REFERENCES

Alonso, K., Bachmann, M., Burch, K., Carmona, E., Cerra, D., de los Reyes, R., Dietrich, D., Heiden, U., Hölderlin, A., Ickes, J., Knodt, U., Krutz, D.and Lester, H., Müller, R., Pagnutti, M., Reinartz, P., Richter, R., Ryan, R., Sebastian, I., Tegler, M., 2019. Data Products, Quality and Validation of the DLR Earth Sensing Imaging Spectrometer (DESIS). *Sensors*, 19.

Bernardo, N., Watanabe, F., Rodrigues, T., Alcântara, E., 2017. Atmospheric correction issues for retrieving total suspended matter concentrations in inland waters using OLI/Landsat-8 image. *Advances in Space Research*, 59(9), 2335-2348.

Brockmann, C., Doerffer, R., Peters, M., Stelzer, K., Embacher, S., Ruescas, A., 2016. Evolution of the c2rcc neural network for sentinel 2 and 3 for the retrieval of ocean colour products in normal and extreme optically complex waters. *Proceedings of the Living Planet Symposium 2016, Prague, Czech Republic, Volume ESA SP*.

DESIS-PAV, 2015. ATDB L1A, L1B, L1C, L2A Processors.

Dierssen, H., Bracher, A., Brando, V., Loisel, H., Ruddick, K., 2020. Data needs for hyperspectral detection of algal diversity across the globe. *Oceanography*, 33(1), 74–79. https://www.jstor.org/stable/26897837.

Giardino, C., Brando, V., Gege, P., , alii, 2019. Imaging Spectrometry of Inland and Coastal Waters: State of the Art, Achievements and Perspectives. *Surv Geophys*, 401–429.

Hestir, E. L., Brando, V. E., Bresciani, M., Giardino, C., Matta, E., Villa, P., Dekker, A. G., 2015. Measuring freshwater aquatic ecosystems: The need for a hyperspectral global mapping satellite mission. *Remote Sensing of Environment*, 167, 181-195. Special Issue on the Hyperspectral Infrared Imager (HyspIRI).

Pahlevan, N., Smith, B., Binding, C., Gurlin, D., Li, L., Bresciani, M., Giardino, C., 2021. Hyperspectral retrievals of phytoplankton absorption and chlorophyll-a in inland and nearshore coastal waters. *Remote Sensing of Environment*, 253, 112200.

Pereira-Sandoval, M., Garcia-Jimenez, J., Blix, K., Ruescas, A. B., Urrego, P., Ruíz-Verdú, A., Delegido, J., Soria, J., Perpinyà, J., Vicente, E., Moreno, J., 2021. Machine Learning Supervised Classifications of Optical Water Types in Spanish Lake Waters. in preparation.

Pereira-Sandoval, M., Ruescas, A., Urrego, P., Ruiz-Verdú, A., Delegido, J., Tenjo, C., Soria-Perpinyà, X., Vicente, E., Soria, J., Moreno, J., 2019. Evaluation of Atmospheric Correction Algorithms over Spanish Inland Waters for Sentinel-2 Multi Spectral Imagery Data. *Remote Sensing*, 11(12).

Pinnel, N., Gege, P., Goritz, A., 2019. The hyperspectral sensor desis for aquatic ecosystem monitoring -a sensitivity study. *EARSeL SIG Imaging Spectroscopy Workshop*.

Stendera, S., Adrian, R., Bonada, N., , alii, 2012. Drivers and stressors of freshwater biodiversity patterns across different ecosystems and scales: a review. *Hydrobiologia*, 1-28.

Urrego, P., Delegido, J., Tenjo, C., Ruíz-Verdú, A., Soriano-Gonzalez, J., Pereira-Sandoval, M., Soria-Perpinyà, X., Vicente, E., Soria, J., Moreno, J., 2020. Validación de productos de clorofila y sólidos en suspensión generados por el procesador c2rcc con los satélites sentinel-2 y sentinel-3 en aguas continentales. *XX Congress of the Iberian Association of Limnology. Online congress*.